NASA-STD-3001 Technical Brief

Sensorimotor Overview

OCHMO-TB-010

Executive Summary

The human body is exposed to numerous health hazards throughout any given spaceflight mission, from suborbital spaceflight to deep space exploration, and ranging from short-duration exposure to long-duration missions of months to even years of continuous spaceflight. During spaceflight, astronauts experience altered gravity environments that lead to sensorimotor decrements, often manifesting as motion sickness, spatial disorientation, problems with postural control and locomotion, and fine motor control deficits. These in turn lead to a decrease in overall crew performance, including difficulties with manually controlling a vehicle, extravehicular activities, and ingressing/egressing the vehicle. The purpose of this technical brief is to provide an overview of vehicle and system design considerations, flight rules and mission operations, pharmaceutical intervention, and crew training and assessments that can minimize the adverse effects of sensorimotor degradation that crewmembers experience during spaceflight.

Relevant Technical Requirements

NASA-STD-3001 Volume 1, Rev B

[V1 4006] In-Mission Fitness for Duty Sensorimotor
[V1 4007] In-Mission Fitness-for-Duty Sensorimotor Metrics
[V1 4008] Sensorimotor Performance Limits
[V1 4009] Sensorimotor Countermeasures
[V1 5009] Physiological Exposure Mission Training

NASA-STD-3001 Volume 2, Rev C

[V2 3101] Iterative Developmental Testing
[V2 5003] Sensorimotor Capabilities

Astronaut David C. Hilmers conducts the Microgravity Vestibular Investigations (MVI) sitting in its rotator chair inside the IML-1 science module

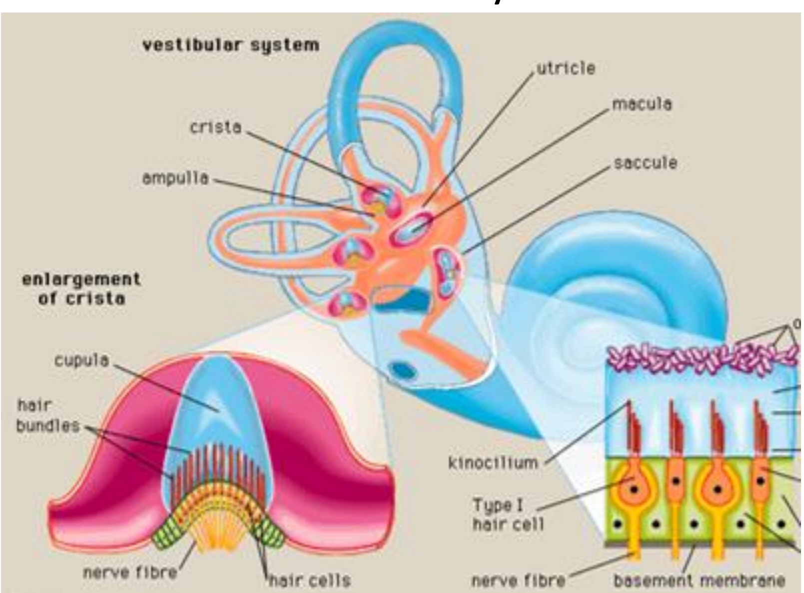
Background

Primarily, the altered gravity environment contributes the greatest amount to changes in sensorimotor and vestibular functioning that manifests as:

- Space motion sickness (SMS),
- Spatial disorientation
- Decrements in postural control and locomotion
- Fine motor control deficits

This in turn creates difficulties in crew performance, such as decrements in manual control of a vehicle, extravehicular activities, and egress during and following gravitational transitions. The outcomes of these decrements are influenced by individual physiological response, vehicle design, and operational conditions (ex. overall deconditioned state of the crew, landing scenarios (water vs. land), operational status (nominal or off-nominal), and mission duration or complexity.)

Human Vestibular System



Evidence from years of human spaceflight has established that sensorimotor alterations, including SMS, vertigo, and vestibular changes, affect astronaut behavior and performance during and following gravitational transitions. These alterations stem from a disruption in the information received through the human sensory systems including the visual, vestibular (information received through the semicircular canals and otoliths), proprioceptive, and tactile systems. These disruptions have a variety of potential causes including fluid shifts, confusion involving ocular/vestibular accommodations, and changes in mechanoreceptors in muscles and joints.

Performance changes can include decrements in visual performance, vestibular-ocular reflex function, eye-hand coordination, postural and locomotive abilities, spatial orientation, and SMS, which causes symptoms similar to other forms of motion sickness such as malaise, nausea and vomiting, and increased body warmth.

Considerations should be taken for the following: adaptability is most difficult during and following G-transitions; subject variability exists between crewmembers; in-flight motion sickness incidence appears to decrease in repeat flyers; and in-flight susceptibility does not necessarily predict re-entry susceptibility.

Reference Data

The primary sensorimotor countermeasures most often utilized during spaceflight include:

1. Vehicle & System Design – System design considerations, in combination with crew training, strategic mission operations, and use of countermeasures and treatment plans, can help to mitigate a large portion of sensorimotor decrements and lead to improved crew performance and overall mission success.
2. Operational Timelines – Reducing the number of critical activities for a defined period post-gravity transition to ensure sensorimotor decrements will not adversely affect crew performance and safety.
3. Pharmaceuticals – Pharmaceutical management of sensorimotor sequelae of spaceflight focuses primarily on prophylactic intervention and/or suppression of motion sickness during and following gravitational transitions.
4. Crew Training and Assessment – Sensorimotor alteration adaptation training targets astronaut behavior, including postural training, proprioceptive training, physical locomotive/muscle strength training, motion sickness training, and sensorimotor and spatial disorientation training. Adaptation training occurs at all stages of spaceflight, including pre-flight, in-flight, reentry, and post-flight. Some of the previous training studies have resulted in training guidance or recommendations that astronauts can elect to use during their own self adaptation training. Crew are not required to complete any specified training but may elect to use training guidance procedures anytime from pre-flight through post-flight.

Additional countermeasures, such as pre-flight and in-flight balance training, and self-administered rehabilitation are currently being examined as potential means to mediate motion sickness and spatial disorientation, and sensory augmentation to assist with fine motor and postural/locomotion control to reduce these decrements.

Flight Engineer Reid Wiseman of NASA takes a ride in a spinning chair as he tests his vestibular system during pre-launch medical tests

Application

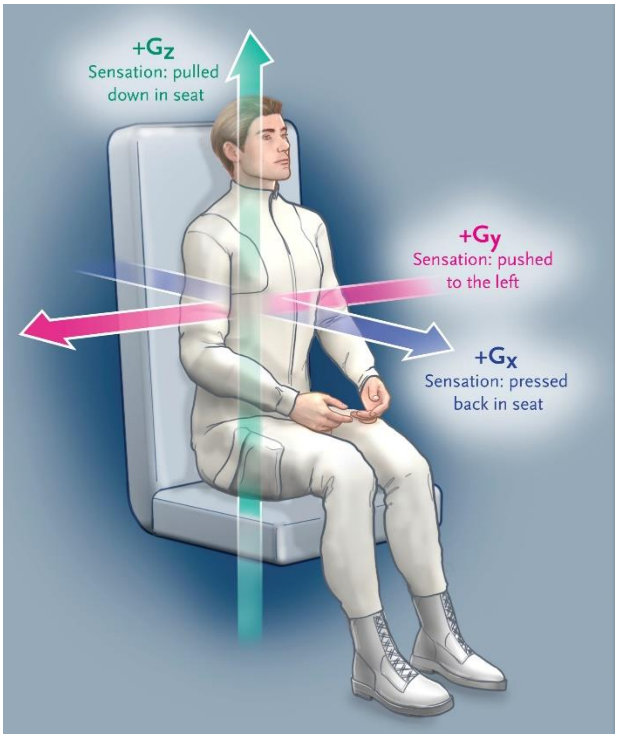
Design Considerations

Engineering and system design must be considered throughout all phases of a mission to address sensorimotor decrements among crewmembers. Vehicle design aspects that may contribute to sensorimotor symptomology include vibration, acceleration and dynamic phases of flight, and crewmember posture and orientation. Other vehicle design factors can help to mitigate sensorimotor decrements or aid crewmembers experiencing sensorimotor symptomology, such as the inclusion of windows, handholds and translational aids, crew interfaces, and vehicle control and automation. In addition, EVA suit and lunar terrain vehicle (LTV) design considerations can be applied to address sensorimotor functioning, both in preventing sensorimotor issues and accommodating crewmembers experiencing symptomology.

Vibration, acceleration, and dynamic phases of flight

The main effects of vibration are experienced by the crew during launch, orbital engine burns, and atmospheric entry phases of a mission. Indefinite exposure to vibration during other phases of a mission can also exacerbate sensorimotor dysfunction among crewmembers. Vehicle and system design can mitigate these effects by reducing both vibration of crew interfaces (i.e., displays) and the physiological levels of vibration experienced by the crew during these phases of a mission.
NASA-STD-3001 Volume 2 provides requirements that limit vibration during pre-flight and dynamic phases of flight, as well as provide guidelines on crew exposure to vibration for long-duration missions and limits to prevent degradation of crew performance.

During vehicle acceleration and dynamic phases of flight, crewmembers are susceptible to large amounts of sensorimotor degradation. Both linear acceleration and rotational motion during flight impairs sensorimotor functioning of the crew. Sustained transverse-axis g loading also plays a significant role in crew sensorimotor functioning with significant impacts on human visuomotor performance. *NASA-STD-3001 Volume 2 enacts requirements for both spacecraft and rovers that provide guidelines for sustained translation acceleration limits, rotational velocity, and transient rotational acceleration in-part to reduce sensorimotor degradation among crewmembers.*



Acceleration Vectors and Associated Sensations

Application

Crewmember posture and orientation

Crewmember posture and orientation, particularly position of the head, is an important variable in sensorimotor functioning. For example, crewmembers are less likely to feel vestibular disturbances when seated at a raised angle during vehicle motion versus a fully reclined position. Additionally, there are less disturbances to sensorimotor functioning when crew are facing the direction the vehicle is traveling. Tilting of the head during various phases of flight can contribute to sensorimotor dysfunction, with gravity environment adaptation and crew deconditioning greatly contributing to hypersensitivity to head movement. Limiting head movement during certain phases of flight (i.e., manual landing) and maintaining consistent orientation can help reduce these effects. Creating a smaller and more compact vehicle cabin can help to limit head and body movement during certain phases of flight and assist crewmembers in maintaining consistent orientation. *NASA-STD-3001 Volume 2 provides requirements that limit hang time post-landing and posture requirements and use of restraints during various phases of flight.*

Seat roll angle ("clocking" or rotation of seats around the vehicle x-axis) and resultant occupant body roll angle within the vehicle may have a significant effect on the vestibular system, including spatial disorientation.

Orion cockpit layout and crewmember launch orientation

Windows

Strategic placement of windows throughout a vehicle, particularly within a cockpit, provides surface-fixed visual references and visual cues that are consistent with vestibular and tactile cues, helping to reduce sensorimotor issues during piloting activities and gravity transitions. Window views that provide both forward and peripheral views of the horizon can aid crewmembers in maintaining spatial orientation, which leads to better sensorimotor functioning. Considerations should also be taken for the quality of window views with proper depth perception and reduced distortion. *NASA-STD-3001 Volume 2 includes requirements for the provision of windows in vehicles as well as the window optical properties.*

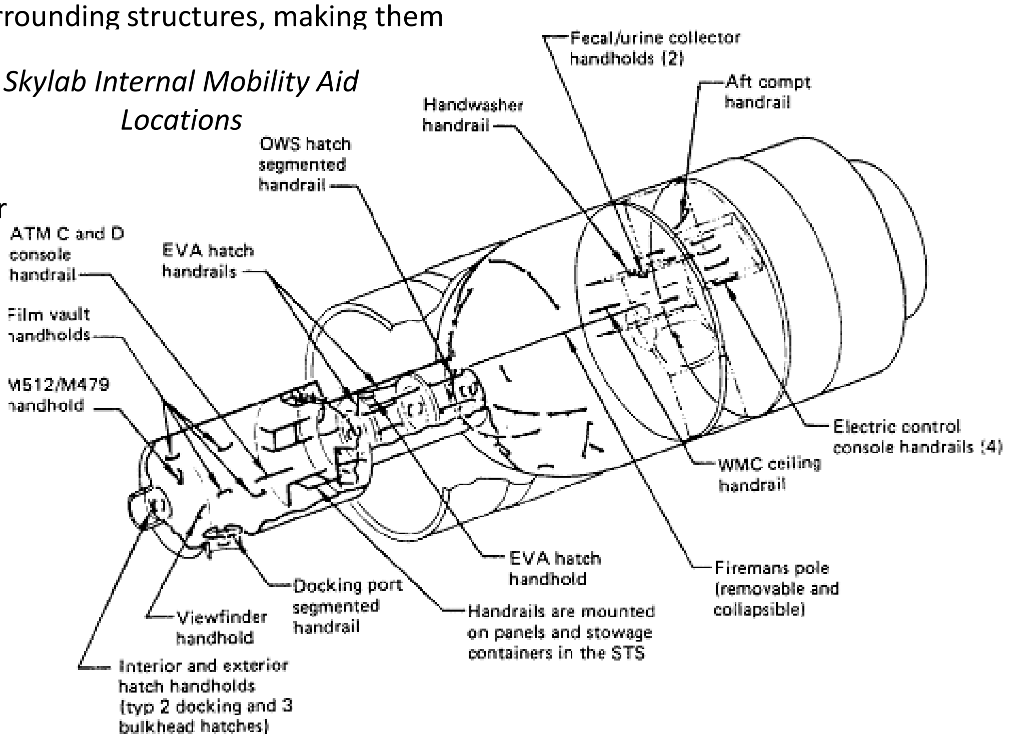
Application

<u>Handholds and translational aids</u>

The inclusion of handholds and translational aids throughout a vehicle allows for crewmembers to safely move about the vehicle, particularly while experiencing sensorimotor issues. Design of hatches and doorways should consider the strategic placement of handholds and translational aids for crewmembers who may be experiencing sensorimotor decrements during ingress or egress activities. *NASA-STD-3001 Volume 2 has various requirements in hatch and doorway design, including guidelines for operating hatches and accommodating deconditioned crewmembers.* Additionally, there are several requirements for the inclusion of mobility aids such as handholds and various restraint devices throughout a vehicle that are quickly discernable from surrounding structures, making them easily recognizable by crewmembers who may be experiencing sensorimotor symptomology.

A requirement for intravehicular paths also levies guidelines for design of translation paths that can be safely accessed by crewmembers in a deconditioned state.

Skylab Internal Mobility Aid Locations



<u>Crew interfaces</u>

A system's crew interfaces are vital components of design when addressing crewmember sensorimotor degradation. Crew interfaces are displays and controls through which static and dynamic information is exchanged between the crew and the system. Well-designed crew interfaces are critical for crew safety and productivity. Crew displays include visual and audio displays, haptic displays, labels, and communication systems. Accommodation of crewmembers who may be experiencing a decrement in sensorimotor processing should include careful consideration of the following: consistent orientation, font sizing and spacing, control locations and procedures, standardization and consistent layout, minimization of crew head movement, stability and reduced vibration of displays, and degraded visual capabilities. *NASA-STD-3001 Volume 2 includes many requirements dedicated to the appropriate design and implementation of crew interfaces, ensuring their usability across each stage of the mission, particularly at times when crewmembers may be experiencing sensorimotor symptomology. Additional requirements provide guidance on designing crew interfaces in relation to crew anthropometric characteristics and capabilities.*

Application

Vehicle control and automation

The design consideration of vehicle controls is closely linked to crew interfaces. Appropriate design of controls and providing intuitive procedures is important in maintaining crewmember spatial orientation. Additionally, manual control interfaces should limit head movement by positioning critical controls within a narrow field of view. Critical switches, levers, and controls must also be safeguarded against inadvertent operation, particularly during off-nominal conditions or when crew may be experiencing sensorimotor decrements. Vehicles should also provide the option of increasing automation levels when the crew's ability to pilot a vehicle is compromised. However, there are important guidelines to follow when developing vehicle automation levels. *NASA-STD-3001 Volume 2 levies requirements for designing and implementing automated systems in vehicles, as well as control operating characteristics and handling qualities of vehicles defined by the Cooper-Harper Rating Scale, and crew interface requirements that provide guidelines to ensure strategic design and placement of controls that are usable by crew during all phases of a mission.*

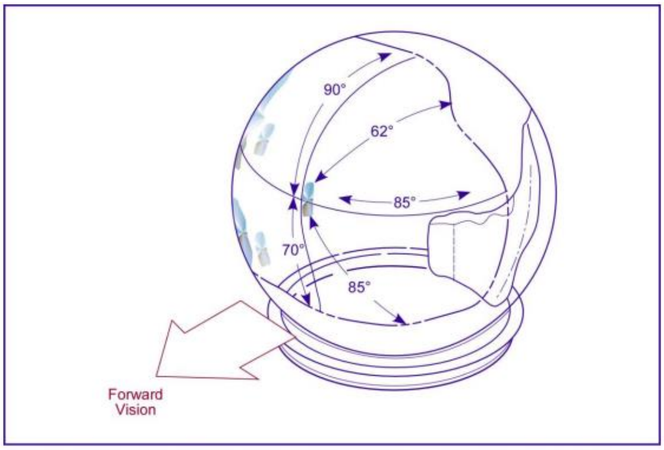
EVA suit design

Vision plays an important role in maintaining sensorimotor functioning of crewmembers in microgravity environments. Thus, considerations for EVA suit helmet and visor design, including optical qualities (i.e., glare, refractive distortion, sunlight attenuation), required head movement, and field of regard, are critical factors in designing for crew sensorimotor decrements. Additionally, crew physical workload while performing suited activities should be considered due to the deleterious effects of physical overload and crew sensorimotor functionality. *NASA-STD-3001 Volume 2 includes multiple requirements for EVA suit design considerations that address these factors, including ability to work in suits (mobility, fatigue, etc.), suited field of view, helmet optical qualities and visual distortions, and physical workload limits. An additional requirement states that suits must have the capability to isolate vomitus in the event that a crewmember experiences spaceflight adaptation sickness (SAS) symptoms or sensorimotor degradation.* The vomitus requirement has not been implemented in past programs due to flight rules that limit EVAs in the early stages of mission (immediately post g transitions) but should be considered for missions that require an EVA immediately post g transition such as landing on a celestial surface.

Summary of Cockpit Design Considerations:

Cockpit Design
- Field of view – full (forward and peripheral)
- Crew position –head and body facing motion
- Instruments and displays – in line with motion
- Controls – intuitive, in line with motion

Technology & Training
- 3D audio
- Tactile displays
- Automation (phase- and task-dependent



EMU Helmet Field of View

Application

LTV Design

Similar to spaceflight vehicles, LTVs must address potential contributors to sensorimotor decrements. Vibration, acceleration, posture and orientation, handholds and translational aids, crew interfaces, vehicle control, and automation may all contribute to sensorimotor functioning of crewmembers utilizing LTVs. It is important to note that crewmembers may also be suited while operating a LTV, adding additional levels of complexity to the design. Pressurized LTVs will also require added attention to windows and crew interfaces. Operational environment considerations will play a role in the overall LTV design guidance, such as expected terrain, angles of translation, etc. LTV vibration design requirements have been developed to provide LTV design criteria to minimize the impact to crew health, including sensorimotor functioning considerations.

Impact of Design on Flight Rules and Operations

When discussing the potential design considerations that can promote mission success by either preventing sensorimotor degradation or accommodating crewmembers with sensorimotor functioning issues, it is important to mention that deliberate and strategic planning during the design phase can play a role in subsequent flight rules for a mission. More specifically, if appropriate design guidance is implemented from the beginning to prevent significant sensorimotor decrements among the crew and/or provide accommodations to crewmembers experiencing symptoms, required flight rules and mission operations are much less limiting. Shorter-duration lunar surface missions will have constrained operational time limits, thus providing a typical 48- to 72-hour adaption after landing on the Moon is not practical. It will be critical to ensure the suit facilitates easy movement and can accommodate vomitus. By designing vehicles/suits/etc. to prevent or accommodate sensorimotor decrements (i.e., providing emesis bags in EVA suits, reducing provocative motions when deploying EVA egress equipment), crew are able to perform mission objectives with less restrictive flight rules.

Example of operational flight rule from the International Space Station (ISS): No scheduled EVAs are to be performed prior to MET 72 hours. *Rationale: During adaptation to zero-g conditions, moving about may provoke symptoms of illness. The activity associated with putting on a suit would increase the chance of an EVA crewmember being ill and potentially endanger the crewmember with vomitus in the suit.*

Application

Stages of a Mission and Relevant Design Considerations

Individual missions are comprised of different stages impacted by several types and degrees of sensorimotor decrements, various combinations of recommended countermeasures and operational rules (for example, limited performance requirements during the first days in orbit, avoidance of EVA during early on-orbit periods, etc.), and resulting design considerations to be incorporated at each stage. The figure below provides an overview of the individual stages of a mission and the recommended countermeasures to be implemented during each time period.

Phases of a Mission and Implementation of Sensorimotor Countermeasures and Operational Guidelines

		Mission Phase										
		Pre-Flight	Launch	Microgravity	Docking Maneuvers	Planetary /Lunar Landing	EVA	Planetary Surface Operations	Terrestrial Landing	Water Landing	Post-Landing	Post-Mission Reconditioning
Countermeasures	Operational Constraints		✓	✓	✓	✓	✓	✓			✓	✓
	Vehicle Design		✓	✓	✓	✓	✓	✓	✓	✓		
	Pharmaceuticals		✓	✓	✓	✓	✓	✓	✓	✓	✓	
	Crew Training	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Pharmaceutical Interventions

In general, pharmaceutical support is considered supplemental to operational actions that limit the provocation of SMS sequelae. However, such operational parameters may not be sufficient to avoid all SMS symptoms. Current clinical practice for the pharmaceutical management of SMS is variable and dependent on the personal preferences of crewmembers and their flight surgeons, individual susceptibility, and prior experience on orbit, if available. Medications commonly used to treat motion sickness terrestrially have had varying degrees of success, including diphenhydramine, dimenhydrinate, meclizine, and chlorpromazine (Barratt, Baker, & Pool, 2019). Case reviews from previous flights have determined that promethazine and scopolamine may be effective treatment options for SMS symptoms inflight (Davis, Jennings, & Beck, 1992; Barratt, Baker, & Pool, 2019).

Research and ongoing studies – Crew training and assessment

Research studies and data collection regarding sensorimotor functioning during spaceflight has been a large area of interest in the past, and ongoing studies continue to develop training strategies that could potentially decrease the impact of sensorimotor alterations on crew health and performance. While there is variability in the utilization of different training and countermeasure implementation and a lack of standard practices at this time, the results from previous research and data analyzation are being considered for further study or treatment options. Sensorimotor countermeasures development is a complicated problem and there are limited countermeasures that have been incorporated to date.

Back-Up

Referenced Technical Requirements

NASA-STD-3001 Volume 1 Revision B
[V1 4006] In-Mission Fitness for Duty Sensorimotor In-mission Fitness-for-Duty requirements shall be guided by the nature of mission-associated critical operations (such as, but not limited to, vehicle control, robotic operations, EVAs).

[V1 4007] In-Mission Fitness-for-Duty Sensorimotor Metrics In-mission Fitness-for-Duty requirements shall be assessed using metrics that are task specific.

[V1 4008] Sensorimotor Performance Limits Sensorimotor performance limits for each metric shall be operationally defined.

[V1 4009] Sensorimotor Countermeasures Countermeasures shall maintain function within performance limits.

[V1 5009] Physiological Exposure Mission Training Physiological training designed to assist crewmembers with pre-mission familiarization to in-flight exposures (i.e., carbon dioxide [CO2] exposure training, hypoxia training/instruction, centrifuge, and high-performance aircraft microgravity adaptation training) in preparation for space flight shall be provided.

NASA-STD-3001 Volume 2 Revision C
[V2 3101] Iterative Developmental Testing Each human space flight program or project shall perform iterative HITL testing throughout the design and development cycle.

[V2 5003] Sensorimotor Capabilities The system shall accommodate anticipated levels of crew sensorimotor capabilities under expected task demands.

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